

# ON THE ASSOCIATION BETWEEN TORNADOES AND 500-MB. INDICATORS OF JET STREAMS

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## ABSTRACT

Many studies of tornado-severe local storms outbreaks have called attention to the role of the jet stream. In fact, the jet has become an accepted part of a climatological model for tornado occurrences in the central and southern Plains. This study undertakes to verify this acceptance by statistically testing the association between 500-mb. indications of the midlatitude and subtropical jet streams and tornado days in Kansas, Oklahoma, and Texas.

The results presented here indicate that indeed the two jet streams are associated with tornadoes. Further, the results are interpreted to show important spatial variations in the relative influence of the two jet streams.

## 1. INTRODUCTION

Meteorological research has often led to climatological models for specific weather occurrences. The tornado is no exception. Bates [2] and later Newton [16] have proposed a simple climatological model for tornado situations in the southern and central Plains. This model is shown in figure 1. The main features are a cyclonically curved jet stream to the west and a low-level moisture intrusion from the Gulf of Mexico.

The basis for this model is to be found in the numerous studies on tornado forecasting conducted since the early 1950's. Fawbush, Miller, and Starrett [6] were among the first to draw attention to the influence of the jet in tornado development. Since that time there has been no dearth of research on the tornado-jet stream associations.

Empirical studies (e.g., Miller [14], Porter et al. [18], Fawbush et al. [7], and Beebe [3]) of the case study type have shown, synoptically, an association between jets and tornado-severe weather occurrences. Other researchers have dealt theoretically with such items as air mass structure and modification (e.g., Beebe and Bates [4] and House [11]), thunderstorm dynamics (e.g., Newton [16]), and thunderstorm mechanics (e.g., Bates [1]). They have considered the ways in which jets can aid in the development of severe local storms and perhaps even in the formation of the tornado itself.

It is apparent that the theory and practical importance of the features of this climatological model for tornado occurrences are well established for relatively short time spans. It is equally apparent, however, that the jet stream has not been subjected to statistical verification over a time period of climatologically significant length. It is the purpose of this paper to report on an attempt to perform such a verification.

The statistical test involves examining the association between tornado days in Kansas, Oklahoma, and Texas and 500-mb. indicators of the midlatitude and subtropical jet streams. The association is checked by applying an analysis of co-variance model to the variables. The results indicate that a significant association of substantial proportions exists.

It is believed that the key to an adequate testing of the jet feature is a long period of record. The use of a large number of cases over a considerable period of time seems necessary on two counts. First, the effect of "textbook" cases which can bias the model is reduced. Second, the year-to-year variability in the association is averaged so that a truer overall picture is obtained. However, a dilemma appears at this point.

The dilemma is this. It is generally recognized that upper tropospheric data are required to precisely locate

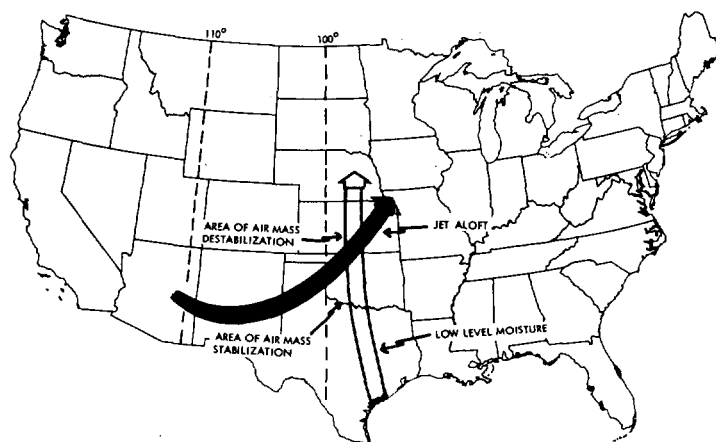


FIGURE 1.—Diagram of climatological model for tornado occurrences in the central and southern Plains after Bates [2] and Newton [16]. Features include an upper-level jet, low-level moisture tongue, and air mass modification.

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jet streams. However, before the mid-1950's, the desired upper tropospheric data are sporadic and somewhat inaccurate at best. Thus, midtropospheric data (500-mb.) must be used to approximate jet stream locations for about one-half of a minimum study period of 1945 through 1960.<sup>2</sup> It is deemed essential to carry the 500-mb. definitions through the latter half of the study period also, because of uncertainty in interpreting the results if the definitions of the variables are changed in mid-study. Thus, one can interpret the results of this study as applicable by inference to jet stream cores at higher levels as I do, or one may view the results as only applicable to a set of defined 500-mb. values. The actual values used to measure tornado activity and jet stream locations will now be discussed in detail. The discussion should aid the reader in how he will interpret the results.

## 2. DATA

The period of study extends from 1945 through 1960. This length is needed to insure a reasonable variety of interannual variability so that some confidence can be placed in the climatological significance of the study. Further, 1945 represents the early limit of readily available midtropospheric data in the form of the Historical Weather Map Series 500-mb. charts.

Since this study is concerned with tornadic systems rather than numbers of tornadoes, it is reasonable to use the tornado day as a measure of activity. A tornado day is defined as a day on which one or more tornadoes occurred in the study area. Further, the climatological records contain ambiguous or spurious funnel sightings. For our purposes tornadoes are defined as funnel and/or rotary clouds seen on the ground or having damage associated with them while a short distance above the ground. Finally, only the months of February through June of each year were considered since this well encompasses the major tornado season of the area. Using these criteria and limitations, the tornado days for each State and the three together were abstracted from the usual sources [21, 23, 24].

For each tornado day in the four arrays obtained by the above procedure, the corresponding 500-mb. chart of the Historical Weather Map Series [10, 22] was consulted.<sup>3</sup> From these charts estimates were made of the latitudinal location of the midlatitude and subtropical jet streams within the longitudinal belt 100° to 110° W., since this is the region of greatest cyclonic curvature in the model cited above.

The location of the midlatitude jet stream was estimated on the basis of parameters suggested by O'Connor [17], Fletcher [8], and Dickson [5]. These are: (1) the 18,200 to 18,600-ft. isohyptic channel, (2) the -17° to -21° C. isotherm ribbon, and (3) the band of strongest winds. These three items were considered together subjectively in order to arrive at a single whole-degree estimate of

latitude. In keeping with the climatological model, the latitude was read along the axis of maximum curvature or, if this was not present in the longitudinal channel, at the lowest latitude of the apparent jet stream within the channel.

Preliminary testing showed that in late May and June the midlatitude jet stream alone is insufficient for testing the climatological model. It is reasoned on the basis of Palmén's general circulation model (see [15]) that a subtropical jet stream measure is needed. Unfortunately, no definitive climatological relationships between 500-mb. values and the subtropical jet stream could be found in the literature. However, it was obvious that some type of estimate had to be made.

In the course of inspecting 500-mb. charts for tornado days when the midlatitude jet stream was quite far north, certain associations of height, temperature, and wind speed were noted. There seemed to exist a correspondence between the 19,000 to 19,400-ft. isohyptic channel, the -8° to -12° C. isotherm ribbon, and points of relatively higher wind speed. In addition inspection of maps presented by Huff and Changnon [12], Ramaswamy [19], and Lowe and McKay [13] tended to confirm that these would serve as the best 500-mb. estimators of a jet at higher levels. However, in order to reduce the effect of the inadequacies of these measures, subtropical jet stream data were collected on a class basis. There were three classes employed: (1) no subtropical jet stream, (2) subtropical jet stream at 35° N. latitude or less, and (3) subtropical jet stream at greater than 35° N. latitude.

The result of these data collection procedures is four data arrays—one for each of the three States of Kansas, Oklahoma, and Texas, and one for the study area as a whole. Within each array each tornado day is listed along with the appropriate midlatitude jet stream latitude. These are then stratified in each array on the basis of the classes of the subtropical jet stream.

One additional manipulation is required before a co-variance model can be applied to these data, because any numerical value which each tornado day can assume is a constant. It is obvious that if  $y_i$  is a constant, then  $\sigma_y^2$ , the variance of  $y$ , must be zero. To circumvent this problem, the number of tornado days per one-degree increments of the midlatitude jet stream were summed for each strata of each array. This of course provides for variation of  $y$ .

## 3. MODEL

An analysis of co-variance model as described by Hagood and Price [9] was applied to each of the four arrays. This model has the advantage of parametrically testing the association between variables for which suitable numerical values exist, i.e., tornado days and the midlatitude jet stream. At the same time, the effect of the non-parametric variable, i.e., the subtropical jet stream, is taken into consideration. Essentially, the association is tested by the correlation between the parametric

<sup>2</sup> This study was completed in 1962-63.

<sup>3</sup> This was the case except for 1960 and a few other random dates when the *Daily Weather Map* 500-mb. charts were used.

variables under two conditions: (1) the non-parametric variable is ignored, and (2) the non-parametric variable is held constant.

Intuitively, it is realized that the functional relationship between tornado days, the dependent variable, and the latitude of the midlatitude jet stream, the parametric independent variable, is not linear in form. Preliminary graphic display of the relationship indicated that a curve of the form shown in figure 2 would be suitable. The computational form of this equation can be written as:

$$\log Y = \log a + b \log X + c (\log X)^2 \quad (1)$$

where  $a$ ,  $b$ , and  $c$  are least squares constants,  $Y$  is the number of tornado days, and  $X$  is the latitude of the midlatitude jet stream.

Equation (1) is the one used for computational purposes in the parametric portions of the analysis of co-variance model. The results of the computations are shown in table 1. In this table, the statistical significance is estimated by the  $F$  ratio.

#### 4. RESULTS

The results of the statistical tests are given in table 1. All four test units (the three States separately and combined) show a highly significant association between tornado days and the midlatitude jet stream when the subtropical jet stream is held constant. I have also shown in the larger study on which this paper is based that this association exists even when the subtropical jet stream is not considered at all [20]. Clearly, the midlatitude jet stream is associated with tornado occurrences over the whole of the study area, although, as will be shown shortly, there are variations in the degree of association.

The association between tornado days and the subtropical jet stream when the effects of the midlatitude jet stream are taken into consideration shows much more variation. The most obvious result is the lack of a significant association in Oklahoma. The literal interpretation is that tornado days in Oklahoma are not greatly influenced by the subtropical jet stream. This, however, seems strange since both the Kansas and Texas units show significant association between the variables. The actual reason for this anomalous situation is not

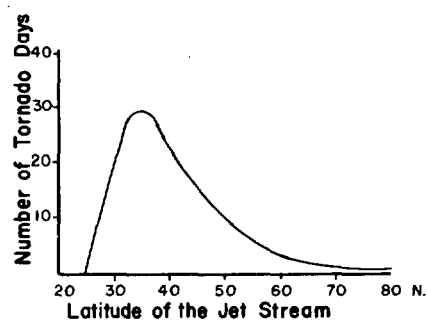


FIGURE 2.—Schematic diagram of the functional relationship between the latitude of the midlatitude jet stream and tornado days.

known. However, one may speculate that Oklahoma is being in effect "skipped over" by the subtropical jet stream. This could occur if the general circulation underwent a very rapid change in early June or late May as suggested by Yeh et al. [25].

Next, the degree of association between the variables may be commented upon. In the case in which the effects of the subtropical jet stream are neglected, the association between tornado days and the midlatitude jet stream for Kansas and Oklahoma is moderate to close. In the Texas and total study area relatively low associations are noted. However, when the effects of the subtropical jet stream are taken into consideration, the picture changes greatly, for now all test units show improved amounts of explained variation.

It is probably fair to say that the changes in  $R$  and  $R^2$  induced by considering the effects of the subtropical jet stream are indicative of the relative importance of the two jet streams. It appears that the subtropical jet stream is as important as the midlatitude jet stream in the Texas test unit where the value of the coefficient of determination is doubled. This would be expected on the basis of the relative location of Texas and the usual position of the subtropical jet stream. Among the three State test units, Kansas has the next greatest increase in explained variation and Oklahoma the least. This too would be expected since the non-parametric tests cited earlier did not indicate a significant association for Oklahoma. Over the study area as a whole the degree

TABLE 1—Results of the analysis of co-variance tests

	Kansas	Oklahoma	Texas	Total area
Association between midlatitude jet stream and tornado days when subtropical jet stream constant?.....	yes	yes	yes	yes
Statistical significance.....	0.001	0.001	0.001	0.001
Association between subtropical jet stream and tornado days when midlatitude jet stream constant?.....	yes	no	yes	yes
Statistical significance.....	.01	-----	.05	.01
Degree of association between midlatitude jet stream and tornado days disregarding subtropical jet stream:				
$R$ .....	.61	.64	.50	.53
$R^2$ .....	.37	.41	.25	.28
Degree of association between midlatitude jet stream and tornado days considering subtropical jet stream:				
$R$ .....	.75	.72	.70	.69
$R^2$ .....	.56	.52	.49	.48

of association is greatly increased when the effects of the subtropical jet stream are considered.

Perhaps the most important result of taking account of the subtropical jet stream is the reduction in the range of explained variation among the four test units. This indicates that the relationship is similar over the whole of the area if the combined effects of the two jet streams are considered. This is somewhat different from the implied dependence on the midlatitude jet stream found in earlier studies. It also seems likely that the subtropical jet stream becomes more and more important as the tornado season progresses since it usually is May and June before it can be well recognized at higher latitudes in the longitudinal belt studied here.

## 5. SUMMARY AND CONCLUSIONS

If the 500-mb. indicators used for estimating the jet stream locations are interpreted as valid approximations, then the following conclusions would appear also to hold:

1. There is a definite space-time variation in the influences of the midlatitude and subtropical jet streams.

2. The association between tornado days and the midlatitude and subtropical jet streams is shown to exist in a climatological sense.

3. The midlatitude jet stream is more important at higher latitudes and the subtropical jet stream at lower latitudes.

4. When both jet streams are considered, the degree of association is close. This indicates that both jet streams must be considered in the dynamic climatology of tornado occurrences.

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